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COMBAT SYSTEMS VISION 2030: FUNCTIONAL ARCHITECTURE FOR FUTURE SHIPBOARD COMBAT SYSTEMS

BY JAMES R. POLLARD
COMBAT SYSTEMS DEPARTMENT

SEPTEMBER 1991

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NAVAL SURFACE WARFARE CENTER

Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

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FOREWORD

As the decade of the eighties came to a close, the Navy surface warfare community found itself in a changing world. Changes in the Soviet Union and Eastern Europe were creating uncertainty in the future missions and roles of the Navy. Advances in technology, particularly in computer-related fields, were suggesting significant changes in shipboard combat system designs. Major ship building programs were beginning to consider next generation designs. Against this backdrop of uncertainty, the Naval Surface Warfare Center's management decided to develop a "vision" of the future surface Navy. There were three fundamental reasons for developing such a vision. The first was to serve as a framework for determining future technology thrusts and investment by the Center. The second was to set a tone for the center to foster a new culture of leadership in combat system engineering. The third was to serve as a catalyst for the surface warfare community in developing its own vision of the future. The time frame for the vision was set at 2030, since today's fleet, given a 40 year service life for ships, must be completely replaced by 2030.

The first step in this effort was to construct a set of plausible alternative geopolitical and military futures. Alternative concepts of Navy missions and roles, warfighting goals, forces and ships were then considered against the alternative futures. The second step was to characterize and set goals for shipboard combat systems in the 2030 time frame, based on the futures analysis. There were two key objectives: (1) to define a combat system architecture framework, with associated system engineering goals; and (2) to articulate a set of technology goals, framed on system concepts. The technology goals would be tailored to yield significant leverage in meeting the warfighting goals identified in the alternative futures context.

This report describes a functional architecture for combat systems in the 2030 time frame. It is the first of four planned reports on combat system architecture and system engineering topics. Other reports will deal with derivation of the architecture, the technical and engineering problems associated with realization of the architecture in physical combat systems, and a set of analytical experiments that can be conducted to develop the scientific and technical underpinnings of combat system architecture and design work.

Approved by:

CARLTON W. DUKE, JR., Head
Combat Systems Department

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ABSTRACT

A combat system architecture for future surface combatants is described. The purpose of this functional architecture is to provide a framework for developing combat system design concepts for the next century. It is part of an overall NAVSWC effort aimed at developing a vision of future naval warfare. The architecture is described in terms of basic warfighting and battle management functions and their relationships. Weapon systems, which represent the warfighting systems to be managed and controlled, and their functions are discussed first as independent entities. Coordination functions are introduced to provide improvements in performance. The weapon systems are organized to best span the battle space and a hierarchical warfare area coordination structure is presented for a single ship. The dynamical properties and operating concepts of the structure are discussed. The information flows in this structure are also presented as well as external sources of information and support. For multiple ships, a force, a hierarchical warfare area coordination structure, similar to that of a single ship is described.

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1.0 INTRODUCTION

In the report that follows, a functional architecture for future combat systems is evolved. Such an architecture represents the structured tasks that must be carried out by a combat system to achieve its warfighting objectives. It consists of a complete set of combat system tasks or functions that have been grouped into distinct domains. A complete set of properly grouped warfighting functions for a single ship will be called a combat system (functional) architecture.

The combat system architecture presented in this report builds on the earlier work of Lindemann (1980), Cullen (1981), and others. This earlier work was concerned with combat system designs for ships of the day and focused on battle management for simultaneous actions in multiple warfare areas. The approach taken was to define a battle organization structure for a single ship based on the Chief of Naval Operation's newly (at that time) issued warfare mission area operating philosophy and then to identify tasks or functions to be carried out by the members of that organization. From this a combat system architecture was formed.

The architecture presented in this report is intended to provide a framework for developing combat systems design concepts for the 2030 time frame. The approach taken in developing such an architecture starts with weapon systems and their functions as the basic building blocks or structural elements of combat systems. With these, the architecture is developed using an approach drawn from the theory of hierarchical control of complex systems[1] with the weapon systems representing the "plant" to be managed and controlled. As such, they are arranged horizontally, to best span the battle space to carry out the ship's missions with vertical layers of coordination imposed on them for battle management and control. A warfare areas grouping of weapon systems was selected as the best horizontal arrangement for coordination. Figure 1 below is a top level view the combat system architecture developed. Shown are three levels with the weapon systems at the bottom and two higher levels for coordination; one for the warfare area weapons and the second for the overall combat system. Three major paths for information transfer and control are also highlighted; the horizontal warfighting paths of the weapon systems and the two vertical paths for coordination. Since the warfare areas are used as an organizing structure what results for a single ship is similar to the earlier work cited. However, the viewpoint presented here provides for an expanded view of weapon systems and sensors architectures and is easily extended to a force architecture for coordinating geographically distributed weapon system functions; a topic not covered by the earlier work.

[1] References are provided for the reader interested in an overview of the theory of hierarchical control of complex systems. Özgünner (1989) provides a good survey as a starting point.

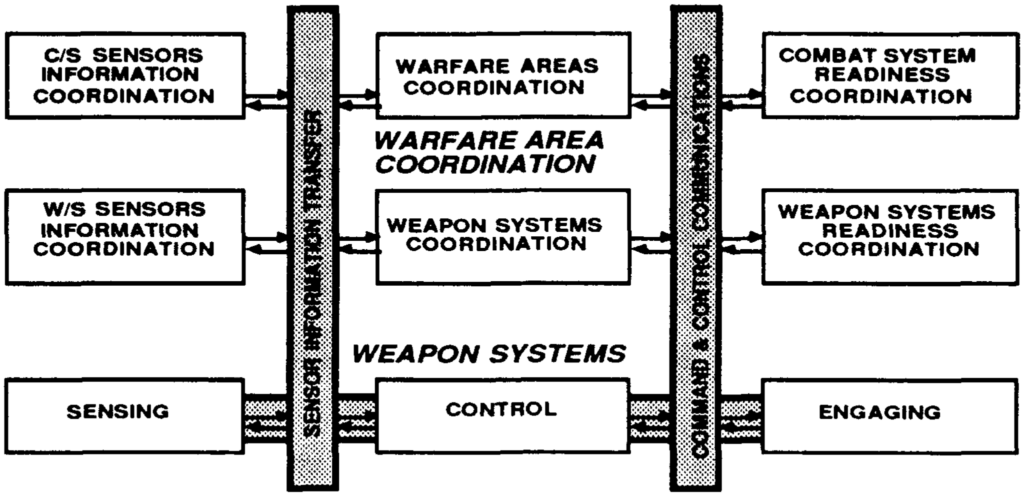

FIGURE 1. A COMBAT SYSTEM FUNCTIONAL ARCHITECTURE OVERVIEW

Before moving on, one more point about architecture should be made. There are two types of architectural descriptions in common use. One is functional as we have discussed, and the second, physical. A physical architecture, as its name implies, is the arrangement of the physical components of a system that constitutes its configuration or packaging concept. The components are usually either equipments, computer programs or people. It is these physical components that actually carry out the functions or tasks of the system. The functional architecture of a system (how we arrange system functions) and the physical architecture (how we arrange the components that carry out those functions) are not necessarily the same. In this report, we will deal only with functional architectures. It is useful at times to use physical systems as examples to aid in understanding and we will do so in this report. However, the reader is cautioned not to view the functional architecture presented as a physical one or as a real system.

This report describes the architecture in a bottom-up fashion. Section 2 begins by examining weapon system functions and defining architecture. In Section 3, the coordination of weapon systems for warfighting is discussed. Section 4 looks at the management of sensors and weapon systems themselves as systems and how they support the warfighting coordination functions discussed in the previous section. Section 5 organizes coordinated weapon systems to best span the battle space and develop a coordination structure for battle management and control that forms a single ship combat system architecture. Section 6 examines this architecture in terms of the information flows within the structure arriving at the so called "H" Architecture view that stresses battle management for a single ship. Section 7 discusses the architecture's interfaces with the ship systems and the sources of information and support from outside the combat system. Section 8 shows how the single ship architecture can be extended to the force level where weapon systems distributed across many ships are now coordinated. And finally, Section 8 summarizes and discusses some of the implications of the architecture set forth.

2.0 WEAPON SYSTEM FUNCTIONS

Weapon systems have as their principal objective to destroy or disrupt enemy systems or targets. To accomplish such an objective, a weapon system must perform certain tasks or functions. Figure 2 shows these weapon system functions for a typical weapon system. The functions are shown in sequence of occurrence or functional flow and have been grouped into three fundamental weapon system functions; sense, control, and engage. These sequenced functions form a *warfighting path* that represents the end-to-end processing of a target. The warfighting paths are the fundamental entities in such a transaction-based combat system. A combat system will typically be made up of many of these warfighting paths. However, the functions that make up a warfighting path may vary somewhat from weapon system to weapon system. The one shown in Figure 2 is for a typical antiair warfare (AAW) weapon system. After examining the functions associated with many weapon systems or warfighting paths, the fundamental sense, control, and engage functions were found to exist in all of them.

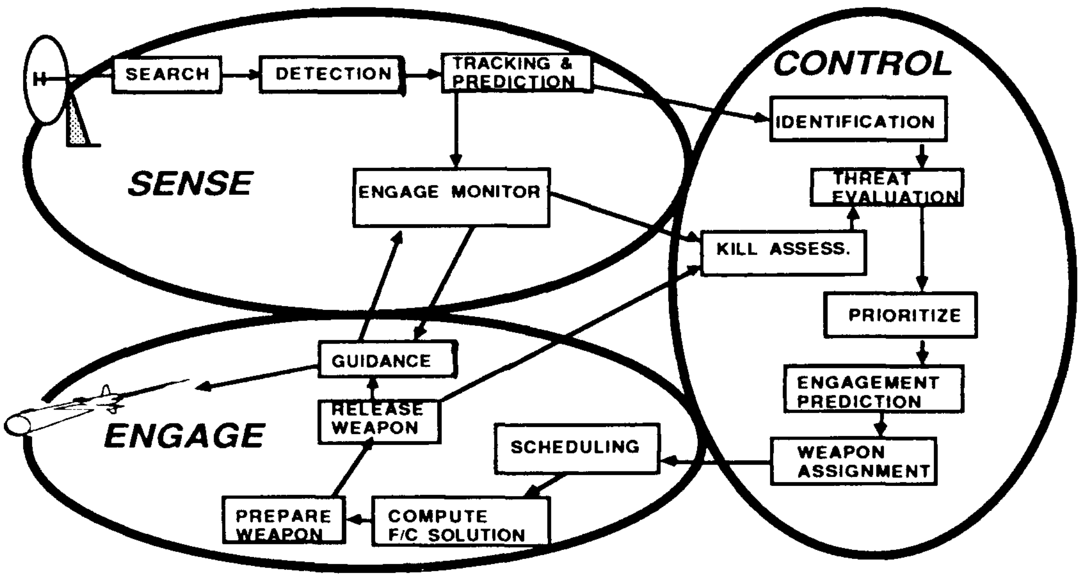

FIGURE 2. REPRESENTATIVE WEAPON SYSTEM FUNCTIONS

That is, all weapon systems were found to ***sense**, to gather target and environment information such as a targets position over time* , to ***control**, to evaluate and decide to take action against a target*, and to ***engage**, to deliver energy to the target.* Thus, the specific functions for any weapon system can be grouped into these three fundamental functions.

Figure 2 constitutes a functional architecture for a weapon system. A functional architecture again is nothing more than a grouping and arrangement of functions. The sense, control, and engage grouping, as shown, was the one selected as the preferred functional grouping for our weapon systems architecture. There were two main reasons for selecting this grouping. First, each of functional groups occupies a clear and distinct domain within the weapon system with their individual and aggregate performance closely coupled. The second is that the action path, the number of steps or stages needed to complete an engagement cycle, is kept to a minimum of three

stages. Short action paths are required for quick weapon system responses. Thus, sense, control, and engage becomes the first grouping of functions in our task of creating a combat system architecture.

3.0 WARFARE COORDINATION

Weapon systems represent the "plant" of a combat system whose fundamental purpose is to process targets in some fashion. Weapon systems that can process targets faster and more effectively than those of the enemy win wars. By coordinating weapon systems, improvements in performance (efficient and effective processing of targets) can be expected over weapon systems that are operated independently. Figure 3 illustrates independent and coordinated weapon systems. Shown are nominally three weapon systems with each having the fundamental sense, control,

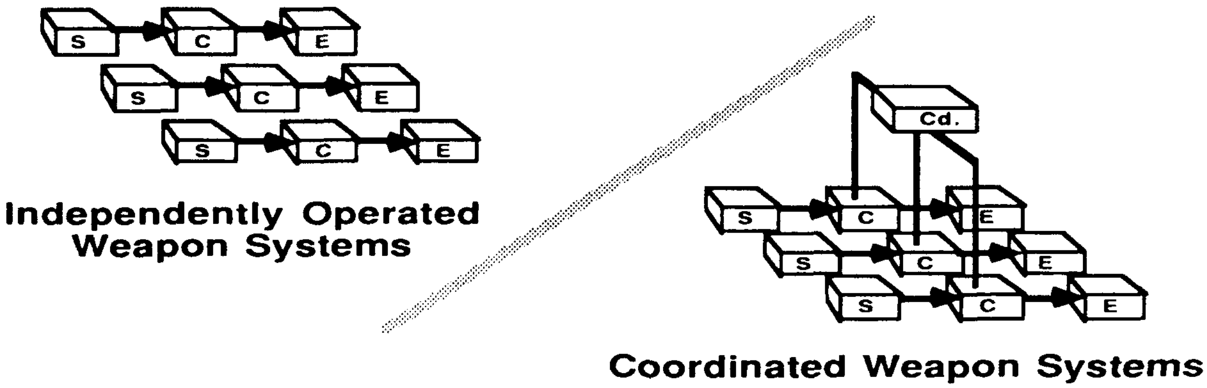

FIGURE 3. INDEPENDENT AND COORDINATED WEAPON SYSTEMS

and engage functions. Physical examples of these might be a gun weapon system, a missile weapon system, and an electronic countermeasures weapon system, all of which are designed to engage air targets at close range. To achieve improved performance, the coordination function must act in some manner on the weapon system control functions as shown. It does so to reduce conflict between weapon systems, minimize resources expended, or in general to make the weapon systems mutually supportive.

The goal of coordination is to achieve optimum overall operational performance for the weapon systems. Optimum performance might be defined as maximizing the cumulative probability of kill of the weapon systems in minimum time with minimum ordnance expended. In achieving this goal, the weapon system coordination function carries out the fundamental functions of plan, observe, decide, and act. More specifically, weapon system coordination functions are[2]:

- Operational Planning
- Resource Assignment
- Weapon Systems Configuration Direction
- Situation Assessment
- Action Monitoring & Assessment
- Action Direction and/or Delegation
- Weapon System Override

These functions for the most part are self explanatory. The third function listed, Weapon Systems Configuration Direction, is an important one and will be discussed later in more detail. It suffices to say here that it deals with having the weapon systems set in the proper mode or configuration for best performance for the tasks at hand.

The coordination function is concerned with defining the immediate operational objectives or tasks to be carried out by the weapon systems and ensuring that they are carried out. It represents an elementary level of coordination concerned with the immediate operations of the weapon systems. As such, it tends to follow the dynamics of the weapon systems processes and intervenes accordingly at times within those dynamics. The coordination function also tends to look ahead in time to determine what future actions should be taken by the weapon systems while the weapon systems themselves tend to look ahead only far enough to accomplish their immediate task.

Thus, coordination is achieved through the seamless integration of independent weapon systems into a uniformly operating combat system. However, having said that, at times, autonomous operation of weapon systems is still desirable. This might be the case for a system failure or battle damage. Thus coordination must also allow for such autonomous operation of the weapon systems.

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[2] There are many equally as good ways to define a set of functions that describe how a system achieves its principal objective. In this report, functions will be defined without debate in order to keep the presentation as simple as possible.

4.0 WEAPON SYSTEMS COORDINATION

Improvements in weapon systems performance can also be achieved if they share data or information with each other. As illustrated in Figure 4, a data sharing function can take place either between the sensing functions, the control functions, or the engage functions. An example of shared sensor data is cueing where one sensor informs another sensor that it has detected a target and thereby aids that sensor in detecting the target. For shared control data, an example might be the sharing of threat evaluation or weapon assignment data to avoid conflicts. Shared engagement data might occur when weapon launch scheduling or target arrival times are shared to avoid conflicts or fratricide.

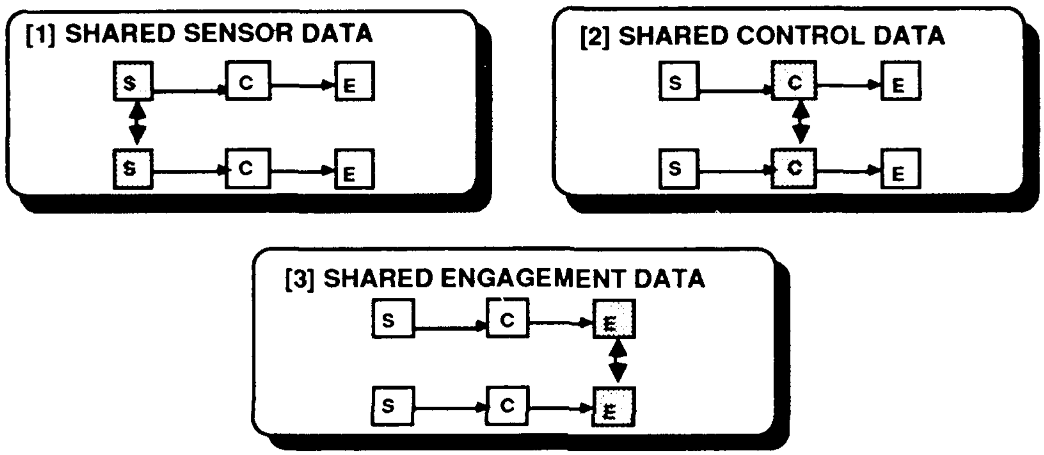

FIGURE 4. SHARING OF DATA BETWEEN WEAPON SYSTEMS

In all cases, the data can be distributed with or without coordination or control. Without coordination, all data is simply made available to everyone. With coordination, data is managed as a resource by a higher authority and allocated as required to the users. Thus, the shared data function can exist at either the weapon system level as a sense, control or engage subfunction, or at the warfare coordination level as a support function, or both.

Next, if we allow weapon systems to share their components with each other, overall improvements in performance can also be realized. Figure 5. illustrates three ways in which weapon systems might share components. First, one weapon system might "borrow" the sensor of another weapon system to carry out an engagement. For example, an electronic support measures sensor could be "borrowed" to fire a missile when the missiles fire control radar (sensor) is being jammed. Second, one weapon system might be used to fire the weapon of another weapon system. A physical example here might be to fire chaff or deploy a decoy against an incoming cruise missile utilizing the radar and control elements of a gun weapon system. The third case is where one weapon system might wish to use the control elements of a second weapon system. A physical example here might be the case where one weapon system has a computer failure or battle casualty and wishes to use the computing resources of another weapon system so that it can engage targets. The basic idea here is to allow for mutual tasking by weapon systems or to be able to configure the weapon system functional components before or during engagements for optimum performance.

Such a sharing of resources requires system coordination; a higher authority which resolves conflict or allocates resources.

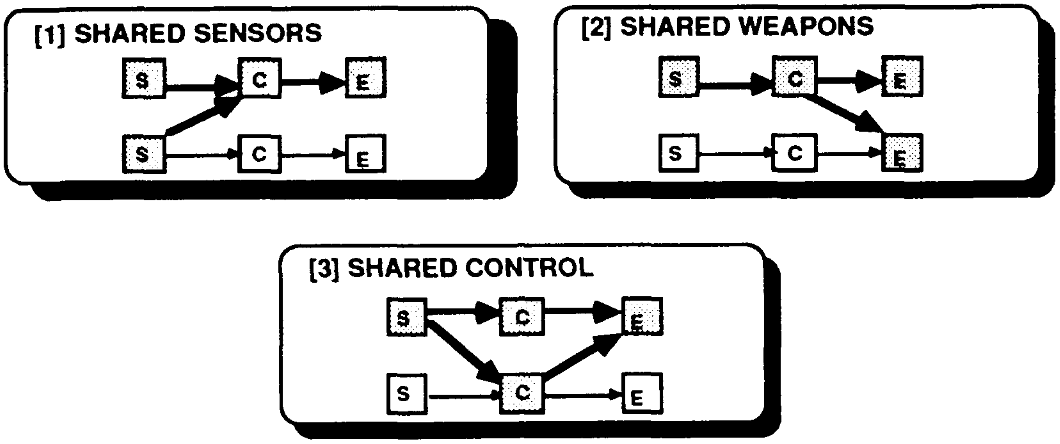

FIGURE 5. SHARING OF WEAPON SYSTEM COMPONENTS

From the above discussions, two major system coordination functions can be identified as shown in Figure 6. First, a sensor system and sensor information management function, is concerned with how to best collect the target or environmental data and how to manage that data to support the weapon system functions. Second, a weapon systems management function is concerned with ensuring that the state of the weapon systems is best for performance. Both of these system coordination functions not only support weapon systems but also support and are subordinate to the warfighting coordination function discussed in the previous section. They supply information needs, principally the operational situation picture and state of the weapon systems, and ensure execution of system related directives.

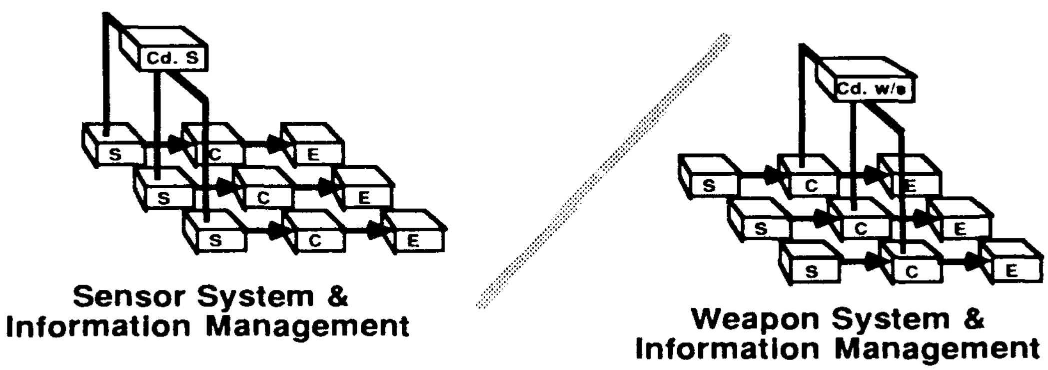

FIGURE 6. MANAGEMENT OF WEAPON SYSTEMS

Sensor system coordination functions (sensor system and sensor information management functions) are:

• Support Operational Planning
• Develop Sensor Operational Strategies and Employment Plan
• Direct Sensors Configuration and Operating Modes
• Form Operational Situation Picture
• Support Threat ID, Classification, and Assessment
• Monitor/Assess the Sensors and Sensors Operational Situation
• Ensure Sensor Information Distribution to All Users

Weapon system (W/S) coordination functions (weapon system and weapon system information management functions) are:

• Support Operational Planning
• Develop W/S Operational Strategies and Employment Plan
• Establish W/S Configuration and Operating Modes
• Monitor and Assess Combat System Performance and Status
• Ensure Weapon System Information Distribution to All Users
• Supervise W/S Repairs and Battle Damage Control
• Supervise W/S Testing & Training

Figure 7 illustrates three fully coordinated weapon systems with the warfighting coordination function and the two supporting systems coordination functions. This arrangement provides for any individual weapon system function to operate independent yet ready for interconnection in any useful arrangement for warfighting. In Figure 7, note that the three coordination functions could have been grouped into one coordination function. Such an aggregation is not uncommon in the control literature. However, here we choose the decomposition shown because the information support functions associated with the two system coordination functions form clear and distinct domains from that of the warfighting coordination function. This choice should become more apparent later in Section 6 when we discuss information and information flows in such a coordinated weapon systems structure.

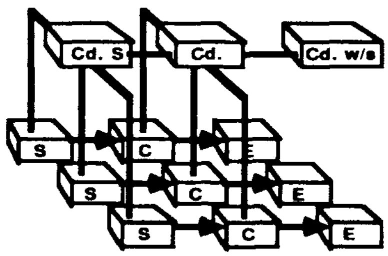

FIGURE 7. FULLY COORDINATED WEAPON SYSTEMS

5.0 THE ORGANIZATION OF COORDINATED WEAPON SYSTEMS

In this section the problem of how to organize and coordinate weapon systems to best perform over the spectrum of ship missions is addressed. The approach is that of hierarchical control theory where the overall warfighting problem is decomposed into simpler and more easily managed subproblems (horizontal decomposition). Coordination of the subproblems (vertical decomposition) is provided so that overall system performance objectives and constraints are best satisfied.

5.1 HORIZONTAL DECOMPOSITION: *ORGANIZING WEAPON SYSTEMS TO FIGHT*

The weapon system warfighting paths have been selected as the fundamental entities of a combat system. We have grouped their functions by sense, control, and engage. This represents one horizontal decomposition that we have made already. The question now is "how do we group these warfighting paths or sense, control, engage functions within a combat system?". The strategy for developing such groupings, horizontal decomposition, is to take advantage of the natural task structure of surface warfare and the fundamental characteristics of the weapon systems that carry out those tasks. What is sought are the warfare tasks that can be carried out as independently as possible with a minimum of interaction with other warfare tasks by a distinct set of weapon systems.

In the volume surrounding a ship, its sensors and weapons form a three dimensional patch work of continuous and often overlapping coverage. The size of volume or battle space and the number of weapon systems needed will depend on the missions and capability for which a particular ship is designed. The problem can then be viewed as one of how to group weapon systems and thereby divide the battle space for ease in carrying out missions.

An obvious natural line of cleavage in the battle space exists between air and underwater. Each has distinctly different warfighting characteristics and employs distinctly different weapon systems against distinctly different targets or threats. Thus, grouping air or AAW weapon systems functions and underwater or antisubmarine warfare (ASW) weapon systems functions, and providing separate warfare coordination for each appears to be a logical decomposition. Indeed after evaluating a number of decomposition schemes, the primary warfare areas of AAW, ASW, antisurface warfare (ASUW), and strike warfare (STW) were found to be the preferred way of grouping weapon systems functions. Figure 8. below illustrates this horizontal decomposition of combat system functions. Note that the decomposition is two dimensional, one being the warfare areas and the other being the weapon systems functions. It is easy to see why horizontal decomposition is often referred to as spatial decomposition.

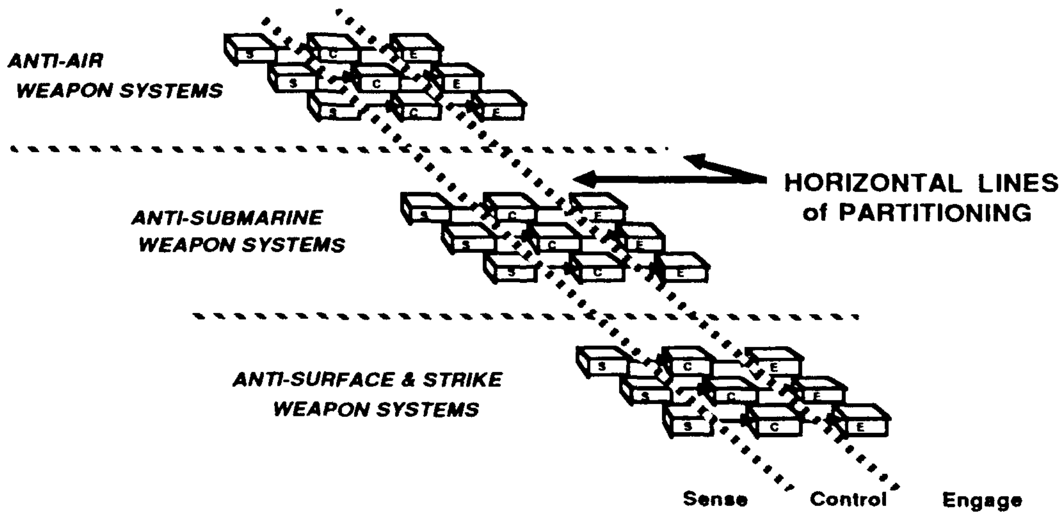

FIGURE 8. HORIZONTAL DECOMPOSITION OF A COMBAT SYSTEM

5.2 VERTICAL DECOMPOSITION: *COORDINATION OF THE WARFARE AREAS*

Vertical decomposition provides for coordination of the warfare area weapon systems functions. Two levels of coordination are identified for a combat system. The lowest level coordinates the weapon systems within a warfare area and the higher level coordinates across these coordinated warfare areas weapon systems. Figure 9 illustrates these two levels of coordination for nominally three warfare areas with three weapon systems each. The lower level of coordination, contains the warfighting and two supporting system coordination functions as discussed in Sections 3.0 and 4.0. These coordinators are delegated to conduct the threat evaluation, weapon assignment, and engagement control functions. Each warfare area has separate coordination and control so the requirement for simultaneous multiwarfare operations can be met.

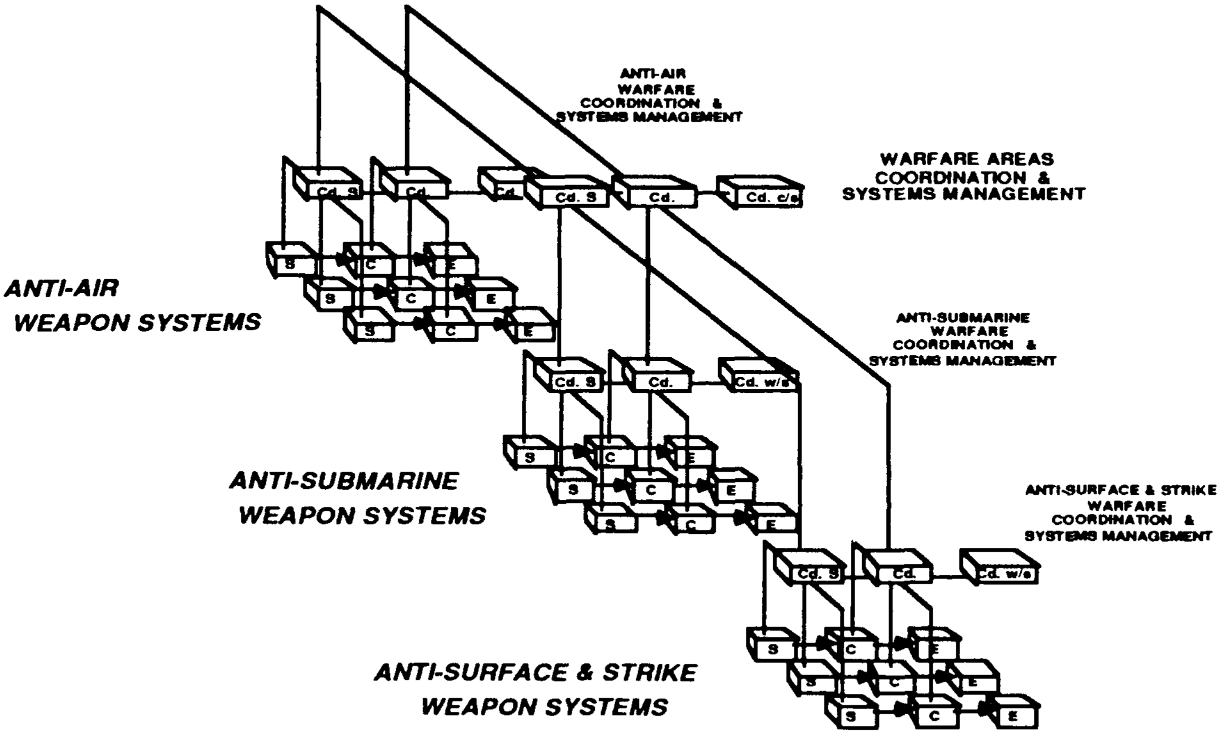

FIGURE 9. FULL COORDINATION OF WARFARE AREAS-A COMBAT SYSTEM

The higher level of coordination, the combat system level, also contains the same three basic coordinating functions. Here, the interactions between air, surface and underwater operations are expected to require minimal operational coordination between warfare areas. Therefore the warfighting coordination function is concerned principally with defining tactical objectives to be achieved by the lower level warfare areas and ensuring that they are successfully achieved. This would be in the form of a mission or tactical plan containing the objectives along with the assigned resources and the constraints and manner in which operations are to be carried out. Examples of the latter one rules of engagement (ROE), emission control (EMCON), etc. Monitoring and assessing the tactical situation and operations and providing appropriate direction to the lower levels are functions carried out to ensure warfare success. As shown in Figure 9. the two management of information and systems functions also support the warfighting coordination function at this level.

Sensor coordination at the combat system level mirrors that for the lower level warfare areas. It consists of two major functional areas; sensor information management and sensor system

management. Sensor information management involves; (a) ensuring that the sensor information gathered by the weapon systems is formed into a consistent tactical picture for warfare area coordination and (b) ensuring that appropriate warfare area sensor information is made available to other warfare areas sensor coordinators and users. The sensor system management function at this level, involves establishing the best strategies or policies for the weapon sensors operations. This includes sensor configuration and tasking functions for optimum information collection across warfare areas and operational functions such as sensor emissions management.

Weapon systems coordination at this level also mirrors that for the lower level warfare areas. It too consists of two major functional areas; overall weapon systems management and the management of the weapon system information required for warfare area and weapon system coordination and management. Weapon systems management includes all functions required to have the weapon systems and their coordination systems in the highest state of readiness at all times and that they are optimally configured for the mission at hand. The former includes such functions as maintenance and training. The latter is a responsibility within the warfare coordination function, but the functions are carried out and supervised within the weapon systems coordination function. Examples include configuration or mode selection for optimum performance or reconfiguration for system failure or battle damage.

Information as to the state of weapon and coordination systems is required by the warfare areas and warfare area weapon systems coordination functions as well as the sensor and weapon system management functions. Weapon systems information management at this level involves functions; (a) to ensure that the information collected by the weapon and coordination systems is formed into a consistent picture of their overall state for warfare areas coordination and (b) to ensure that appropriate warfare area weapon system state information is made available to other warfare areas coordinators.

5.3 INTERACTIONS AMONG THE COORDINATED WARFARE AREAS

Having selected the above decomposition as our functional combat system architecture, three questions now arise dealing with major warfare area interactions. The first is "For weapon systems that carry out multi-warfare area functions, how do you decide in which group to place them?" The second is "Where do anti-C^3I warfare (defeating an enemies C^3I) functions fit in this scheme?" And the third is "How does self defense, which spans all warfare areas and appears to need coordination, fit in this scheme?" Each of these questions is addressed in turn in the following paragraphs.

Where to group multimission weapon systems involves introducing a new idea. The assignment of a weapon systems function to a given warfare area is not a permanent feature but is a dynamic one that depends on the ship's mission and tasks at that point in time. A temporal dimension to our decomposition is thus introduced where weapon systems functions can be moved or reallocated between warfare areas. That is, weapon system functions can be regrouped for coordination to best carry out the ship's immediate mission or task at hand. For example, ASW weapon system functions might be reallocated to ASUW (underwater weapons used against surface ships). Each regrouping of weapon system functions within the warfare areas structure is called a mode of operation. By allowing for any-to-any assignment of warpath functions to warfare areas, a combat system may have a large number of modes. Thus, multiple data and control paths through the combat system are desirable for improved performance by providing for greater operational flexibility, survivability, and growth potential over single path designs.

The situation considered here is not unlike the case of overlapping subsystems, which occurs in certain industrial control applications. In control of large-scale, complex systems, two or

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The situation considered here is not unlike the case of overlapping subsystems, which occurs in certain industrial control applications. In control of large-scale, complex systems, two or

system allowing components to communicate and interact with each other. If this be the case, then recognizing the information transfer functions separately becomes critical.

The weapon systems have information flow paths which connect the basic sense, control, and engage functions, as shown in Figure 10. In the two-way sense to control path segment, target and environmental information from the sensing function flows in one direction and sensor tasking from the control function flows in the other. Information concerning the sensing state is also sent to control to support sensing tasking functions, etc. In the control to engage path segment, engagement orders and information flow one direction and engagement state information flows back. Thus, it is this horizontal flow of messages between the sense, control, and engage functions that completes the circuit and creates a *warfighting path* for processing targets.

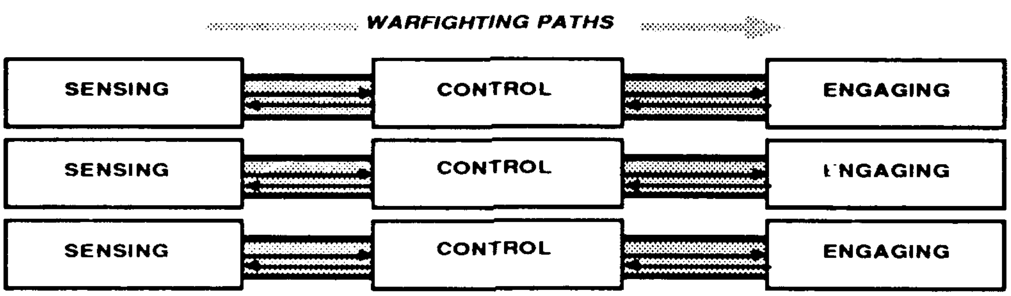

FIGURE 10. THE HORIZONTAL SENSE-CONTROL-ENGAGE WARFIGHTING PATH

Next, the coordination of the weapon systems as shown in Figure 11 is accomplished by means of higher level coordination functions and a vertical communications path for information transfer. In Figure 11, the weapon system and weapon systems information management functions are termed as simply Weapon Systems Readiness Coordination and the path termed Command and Control Communications.

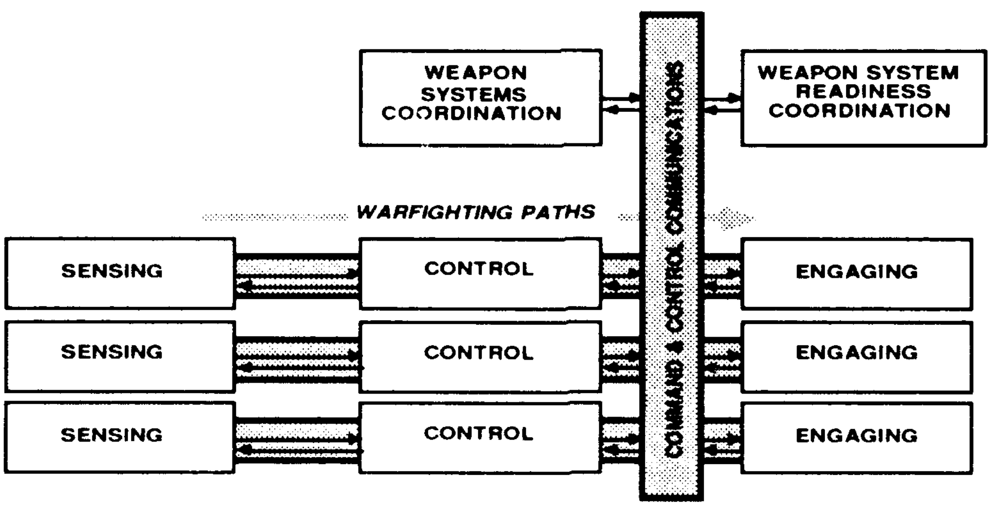

FIGURE 11. ADDING VERTICAL WEAPON SYSTEMS COORDINATION PATH

The information flowing down to the weapon systems consists of operational objectives, operating rules, action directions or intervention and resource assignments. The information flowing up from the weapon systems consists of their current and planned operating processes and states. This circulation of information forms a closed loop that provides for operational control or coordination of the weapon systems. However, such functions cannot be carried out at this point because the target and environmental information necessary for operational situation assessment and decision making is missing.

Figure 12 adds the missing sensor information management function and the path to fully coordinate the weapon systems. The path allows for information flow between the sensing function and the sensor coordination function and the weapon systems coordination function. Again for simplicity, in Figure 12 the former are termed Sensor Information Transfer and Sensor Information Coordination respectively.

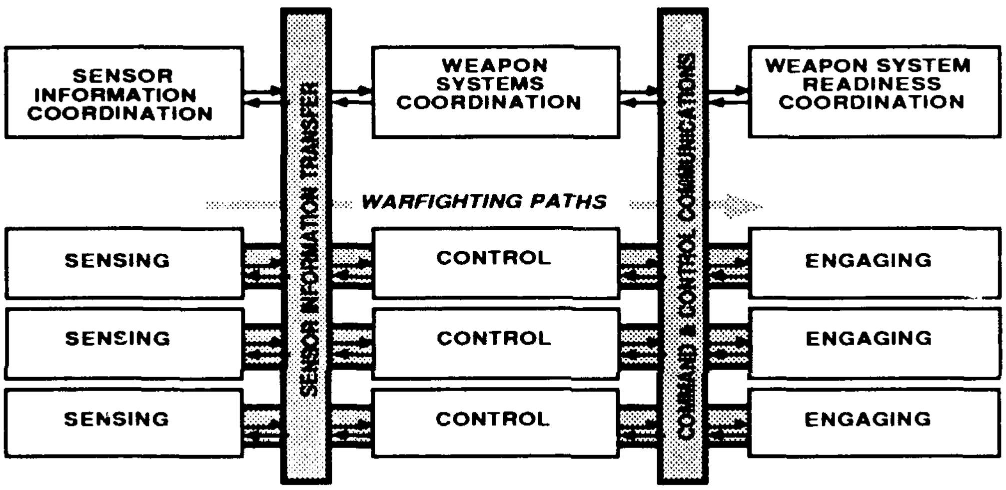

FIGURE 12. ADDING THE VERTICAL SENSING COORDINATION PATH

The target and environmental information produced by the sensors information flows up to the Sensor Information Coordination function where the operational picture is formed. This is furnished to the weapon system coordination function via the Sensor Information Transfer path. Essential target and environmental information is also made to flow between the sensing functions by the Sensor Information Coordination function. Messages flowing down to the sensors consists of operational objectives, operating rules, sensing directives and resource assignments. Note that sensing functions receive direction and can be controlled from two paths. When conflict occurs over sensor control between the Sensor Information Coordination function and the weapon system control function, it is resolved by the Weapon System Coordination function.

Figure 12 represents a group of fully coordinated warfare area weapon systems. Figure 13 shows the full coordination of warfare area weapon systems.

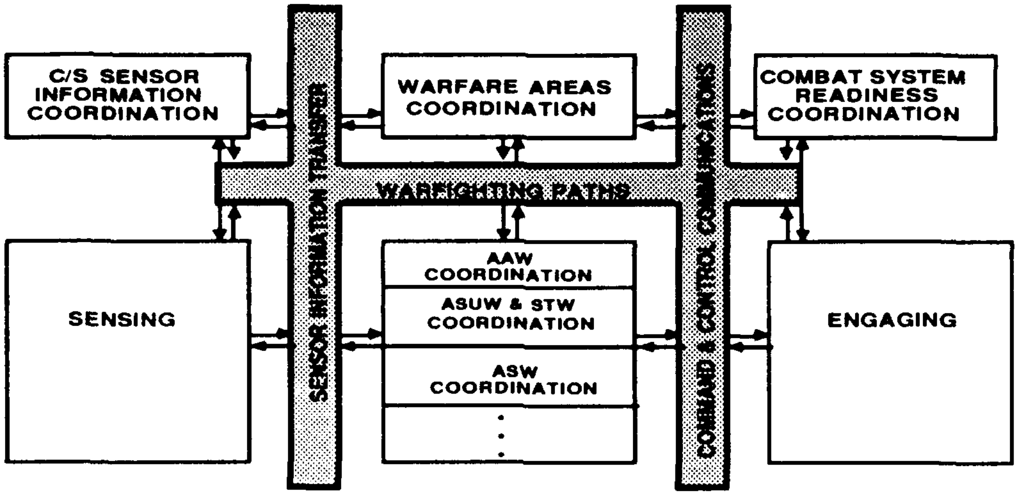

FIGURE 13. SINGLE SHIP FUNCTIONAL ARCHITECTURE REPRESENTATION

Here, the first two layers have been shown as one with the third layer added across the top. The paths for information flow remain the same. In Figure 13, since we have collapsed the lower two levels into one, we represent the warfighting paths simply as a bar path between the levels shown.

The information flowing up from the sensors is the target and environmental information produced by the sensors in each of the warfare areas. To avoid conflicting reports, use of multiple sensor data paths must be avoided. Therefore, the data connectivity digraph connecting each user to his sources of data should be a tree. This information is then formed into a composite tactical picture by the Ship Sensor Information Coordination function and furnished to the warfare area coordination functions via the Sensor Information Transfer path. In this process, information from similar sources should be fused first.

It is commonality of measurement spaces which defines similar sources rather than target type, medium, sensor type, or any of the other reasons which might be invoked to justify a particular data fusion method. This suggests that passive RF-IR/EO intercept data should be fused before fusion with active sensor data and/or imagery is attempted. Precision is not the only factor important in determining the commonality of measurements. Mathematical properties make angle measurement a different process than measurement of range, RF or PRF. Specifically, angle is measured on a compact space. In multi-target tracking, angle track density increases rapidly without limit, even if track density in other dimensions remains small. Association errors then multiply. Another consideration is that whenever possible, data association decision making should proceed from the most accurate sensors to the least. Even if a system employs sophisticated algorithms for data association, the algorithms work most efficiently using the best data first. This principle has major implications for integration of information from offboard and non-organic sensors with own ship's tactical picture as discussed in the next section. In particular, it governs the route which must be followed by arriving sensor reports as they are incorporated into a ship's tactical picture.

The information flowing down to the operational coordination of the warfare area sensors consists of sensing objectives, operating rules, sensing directives and resource assignments. The Ship System Readiness Coordination function mirrors the Ship Sensor Information Coordination function in that it is assembling a "tactical picture" of the combat system in operation and furnishes this to the warfare areas coordination function for taking actions to maintain optimum overall

combat system performance. Thus, the information flows along the two vertical paths between second and third levels of coordination containing the same types of information and messages as between the bottom two levels. However, their content is more aimed at tactical coordination across the warfare areas and intervention at that warfare area coordination level rather than operational coordination of the weapon systems.

7.0 INFORMATION AND SUPPORT FROM EXTERNAL SOURCES

7.1 I & W, TARGET, AND ENVIRONMENTAL INFORMATION

Information from outside sensors and sources supports all levels of the architecture in carrying out their functions. At the lowest level for a single ship external or non-organic sensors can act as virtual sensors that furnish the target and environmental data needed by the control and engage functions to complete the warfighting path for target prosecution. The weapon system control function can also request information or services from these external sources as it would with its own sensors. Figure 14 illustrates this interface at the weapon system level. Also shown are the higher level interfaces for a single ship to the sensor information coordinators.

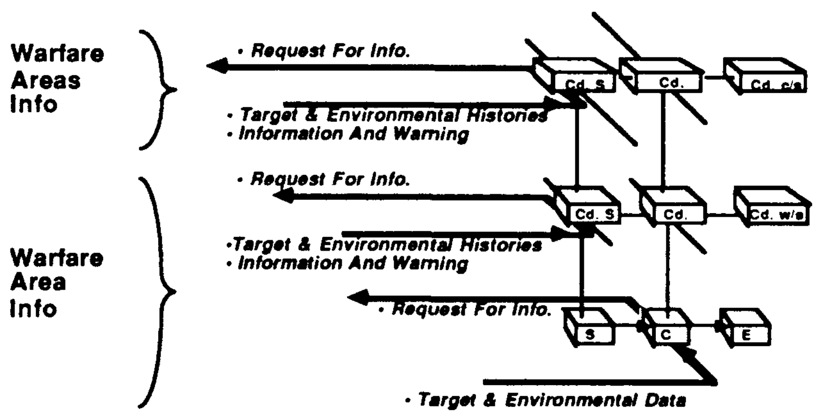

FIGURE 14. EXTERNAL INFORMATION AND SUPPORT FOR A SINGLE SHIP

External information supports the sensor coordination functions of planning, forming the operational and tactical pictures, and monitoring and assessing. These support the warfare area and warfare areas coordination functions. The information consists primarily of environmental and target information and intelligence and warning (I&W). While the type of information is the same at both coordination levels, the content will differ depending on the specific functional needs at each level. One will tend to be warfare area specific and operational in nature while the other is multiple warfare area and tactical in nature. A sensor information coordination function at each level is to ensure that appropriate and consistent information is distributed to all users at their level and below. This implies that external or non-organic information tends to act as if it were flowing down from the top with the lower levels having their information regulated or filtered by the higher levels. However, target and environmental data would enter at the weapon system level to support functions at that level and would tend to flow up as discussed in Section 6.

Force level coordination functions will be discussed in the next section. However, it is mentioned here that external information and support to the force coordination functions will mirror that of the combat system shown in Figure 14. Therefore, without going into further detail, and it suffices to say that the above discussion for the two levels of combat system coordination will hold for the two respective levels of force coordination. Thus, the labels in Figure 14 could be changed appropriately to represent external information and support to the force.

7.2 SHIP SYSTEMS AND CONTROL

The combat system requires support from the ship to carry out its functions. Lindemann (1980) organizes ship support functions into three areas as follows:

- Mobility (propulsion, maneuvering, station keeping, and collision avoidance)
- Containment (damage control)
- Support services (power, auxiliaries, life support, and damage control)

With these functions, a ship systems architecture could be constructed as we have with the combat system. Conceptually, this architecture could be placed alongside the combat system architecture and appropriately tied together to create a total ship functional architecture. However, creating such a description of ship functions and how they interface with the combat system functions is beyond the scope of this report. Here the intent is to simply acknowledge such a functional relationship and in a general way describe the interface.

The warfare areas coordination function is deemed to have the overall responsibility for directing the ship functions in support of the combat system functions in combat. The authority to control specific functions can be delegated to the lower subordinate levels. For example, ship maneuver to say unmask batteries or properly deploy a chaff cloud into the wind could be delegated to the AAW coordinator. Figure 15 illustrates such a simplified interface between ship functions and the combat system functions. Shown is a total ship coordination function that interfaces with the warfare areas coordination function.

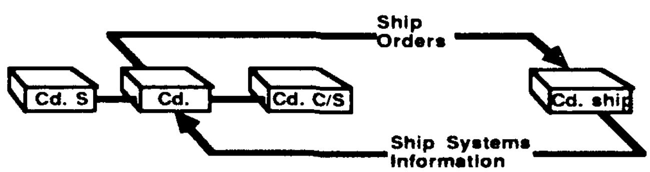

FIGURE 15. SIMPLIFIED SHIP SYSTEMS COORDINATION INTERFACE

Information as to the state of ship functions is furnished to the warfare areas coordinator which in turn issues orders directing that certain functions be accomplished to support combat system actions. Again, an actual functional diagram showing all functional relationships is more complicated than the one shown. It suffices to say that the responsibility for coordination of ship system functions resides with the warfare areas coordinator and the fundamental relationship is as shown.

8.0 FORCE LEVEL COORDINATION OF WEAPON SYSTEMS

While required to fight independently, surface combatants most often fight with other ships as a member of a battle group, surface task group, etc. In this section, the coordination of weapon systems located on many ships is examined. First discussed will be the coordination and control of weapon systems within a force for a single warfare area. Functionally, this will be found to be essentially the same as warfare area-weapon systems coordination for a single ship, but now the weapon systems are geographically separated on different ships. Figure 16 illustrates this case. Each of the ships in the figure has the warfare area coordination of weapon systems as previously discussed, but are now themselves being operationally coordinated by a force warfare area coordination function. This new force level coordination contains the same warfighting, sensors and weapon systems, and information management coordination functions as that for the single ship. They interact with their counterpart at the ship level to operationally coordinate and control the warfare area weapon systems. A description of these functions parallels those presented in sections 3 and 4. Several examples of force warfare area coordination of weapon systems exist today. One is the Tomahawk Afloat Planning System (APS) where the above functions are carried out and individual ships are directed to carry out the weapon control and engage functions by launching missiles at their assigned targets.

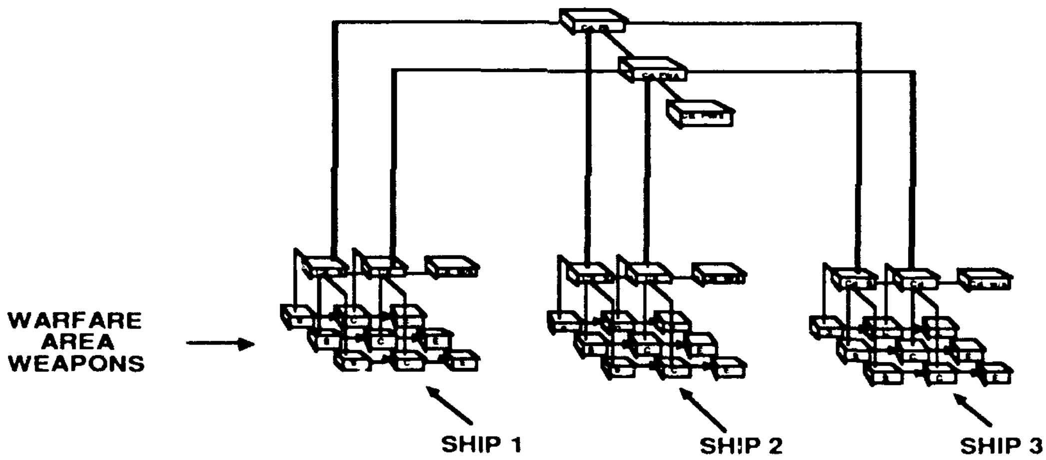

FIGURE 16. FULL COORDINATION OF FORCE WARFARE AREA WEAPONS

There are two coordination functions that support this operational coordination. A description of these functions parallels those presented in Section 3.0 and 4.0. The first of these is force warfare areas sensor coordination (system and information) functions. A current example of this is the AEGIS Cooperative Engagement Processor were the target track information from all SPY-1 radars in the force is combined and linked to all AEGIS ships to form a picture of the operational situation. The second of the support functions is the weapon system and weapon system information management functions. Again, these functions are the same as presented for a single ship in sections 3.0 and 4.0.

Figure 17 illustrates single ship and force coordination of the same warfare area weapons. It appears that the warfare area weapons have two masters to serve; force and own ship! How can this be without conflict? First, the ship warfare areas coordination function has the final responsibility for self defense. Thus, the ship is deemed to always have the control or override

authority of the weapon systems for this case or mode. However for all other cases or operating modes, the control authority over the warfare area weapons resides at the force level. In general, all the offensive actions should be coordinated at force level across all ships. For defense, warfare area coordination can be exercised at force discretion again with single ship override authority. Thus, conflict between ship and force coordination is eliminated by setting the operating mode for the warfare area. Now, the question arises as to how these modes are set and how multiple warfare areas are coordinated at the force level. The answer is force level tactical coordination for the warfare areas.

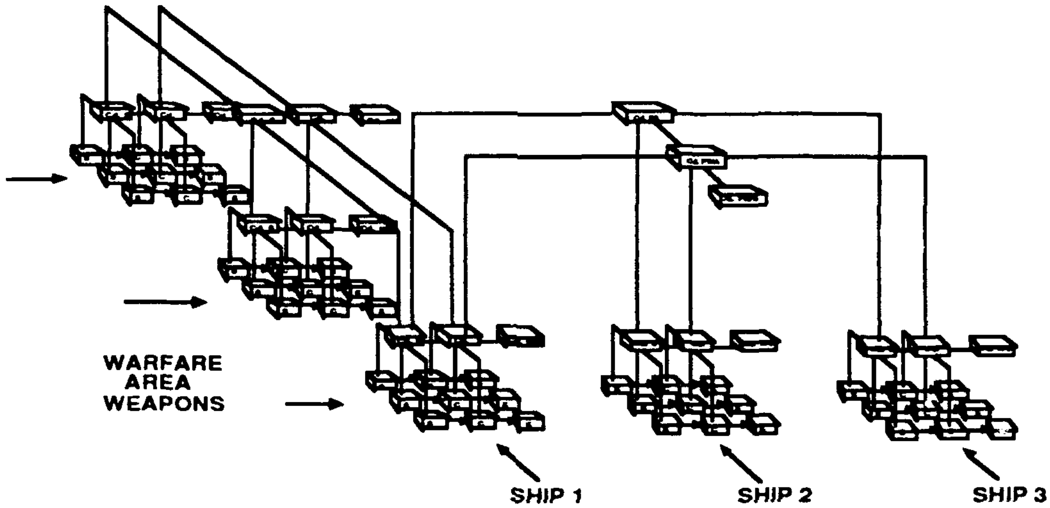

FIGURE 17. SHIP AND FORCE COORDINATION OF WARFARE AREA WEAPONS

Figure 18 shows full coordination of the warfare areas within the force. This is the highest level of warfighting coordination, the tactical level. The warfare areas coordination functions here mirror those of a single ship. That is the force warfare areas coordination functions, the sensor coordination (system and information) functions, and the weapon system and weapon system information management functions shown are the same as those for the tactical level of coordination previously discussed for a single ship.

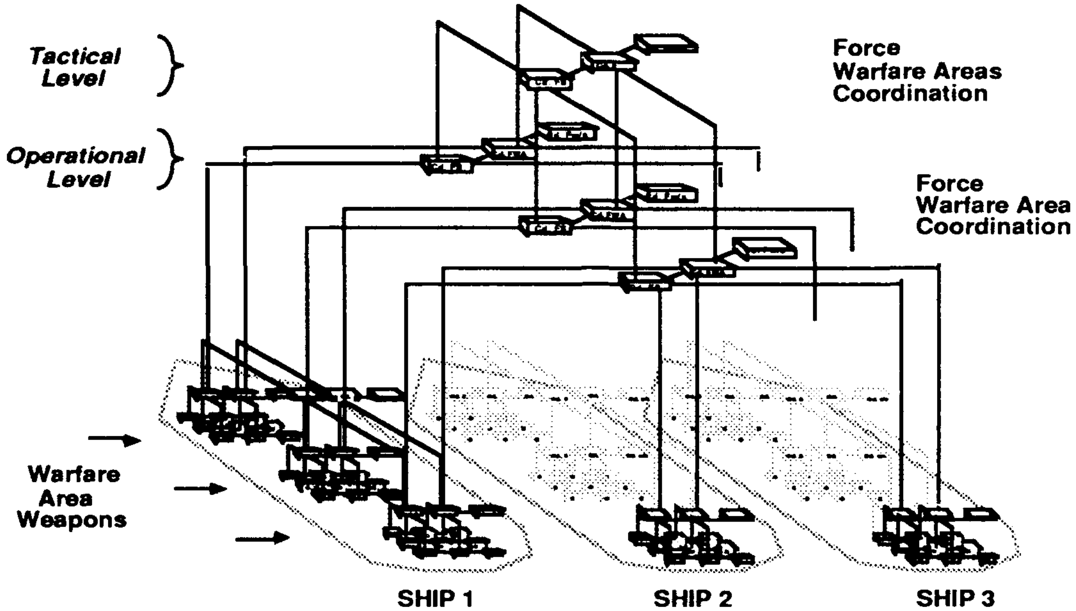

FIGURE 18. FORCE COORDINATION OF WARFARE AREAS

Thus to summarize, what exists here for the force is two levels of coordination for the force and two levels of coordination for the single ship. The operational level at both force and ship is concerned with coordinating weapon systems for optimum performance. The tactical level at both force and ship is concerned with overall battle management and directs the lower level operations in carrying out assigned missions. In force operations, a balance is struck between these overlapping coordination functions by selecting the operating mode that is best to carry out its mission. From the above, one can see that before a command and control system is built, careful consideration must be given to the degree to which higher and lower-echelon systems will interact for coordination and control purposes. Integration at one level can interfere with integration at another.

Before closing out this section, one final comment is in order. Figure 18 shows the sense, control, and engage weapon system functions co-located on a ship. This is done purely for illustration purposes. In general, these can be located on different ships or platforms. For example weapon sensors could be located on an aircraft or unmanned autonomous vehicle, controlled in one ship, and engage weapon launch on a second ship. In this report, we have dealt with functions only and have not intended to allocate them to physical entities which would ultimately carry them out.

9.0 SUMMARY

We have developed a functional architecture applicable to future combat systems for surface combatants. This has been done in a bottom-up fashion starting with weapon systems as the basic building blocks with sense, control, and engage functions. We then created a hierarchical coordination and control structure centered around a warfare areas organization of the weapon system building blocks. We have embedded a number of concepts in this architecture dealing with

operating dynamics. Warfare operating modes with an accommodating flexibility in structure is a principal one. We have illustrated this architecture with what some term "Tinker Toy" diagrams in hopes for clearer communications. Such communication is critical for any vision effort and in the past has been very frustrating at times.

Our purpose for developing the architecture, as we stated at the outset, was to provide a framework for developing a vision of future combat systems for surface combatants. The functional architecture described in this report is intended to provide a template or framework for exploring future combat system design concepts. These design concepts are being based on technology forecasts and assessments and set in the 2030 time frame.

There are four generally accepted views that could be used to describe a combat system structure, all valid and each with its own strengths and weaknesses. One is a mission or organizational view as taken by early combat system architecture researchers. This view decomposes and organizes by mission and then defines a task structure to accomplish the mission or organizational objectives. Sensors gather information needed for task accomplishment and weapons carry out decisions. Such a view tends to emphasize battle management at the expense of sensors and weapon systems. A second view is a functional one such as the one we have taken. Unlike the organizational view, this view tends to be broader and takes into account sensor and weapon structures. A third viewpoint is a state variable one. Here a combat system is characterized by a number of state variables which describe the systems response to inputs. From the state variables, general properties or characteristics of the combat system can be determined. However, state variables themselves are often constructs without a clear physical meaning which leads to problems in interpretation, communication, and understanding. A fourth viewpoint is an object one. Here the combat system is described in terms of physical elements or objects by combining both data and functions associated with the object. The objects would represent the fundamental physical building blocks of a combat system. Proponents believe that "object oriented design" is a better way to achieve modularity. This view point is relatively new and shows promise as a combat system representation. More work remains to assess this approach.

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13. ABSTRACT *(Maximum 200 words)*

A combat system architecture for future surface combatants is described. The purpose of this functional architecture is to provide a framework for developing combat system design concepts for the next century. It is part of an overall NAVSWC effort aimed at developing a vision of future naval warfare. The architecture is described in terms of basic warfighting and battle management functions and their relationships. Weapon systems, which represent the warfighting systems to be managed and controlled, and their functions are discussed first as independent entities. Coordination functions are introduced to provide improvements in performance. The weapon systems are organized to best span the battle space and a hierarchical warfare area coordination structure is presented for a single ship. The dynamical properties and operating concepts of the structure are discussed. The information flows in this structure are also presented as well as external sources of information and support. For multiple ships, a force, a hierarchical warfare area coordination structure, similar to that of a single ship is described.

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